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SEX DIFFERENCES IN INTELLIGENCE AND BRAIN SIZE: A PARADOX RESOLVED

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Summary—Males have larger brains than females, even when corrected for body size, and brain size is positively correlated with intelligence. This leads to the expectation that males should have higher average levels of intelligence than females. Yet the consensus view is that there is no sex difference in general intelligence. An examination of the literature shows that the consensus view is wrong. Among adults, males have slightly higher verbal and reasoning abilities than females and a more pronounced superiority on spatial abilities. If the three abilities are combined to form general intelligence, the mean for males is 4 IQ points higher than the mean for females. Among children up to the age of around 14 yr the sex differences are smaller because girls mature earlier than boys. The evolutionary selection pressures responsible for greater intelligence in males are discussed.

INTRODUCTION

A paradox concerning sex differences in intelligence and brain size has recently been noted by Ankney (1992) and Rushton (1992). This is that males have on average larger brains than females, even when adjustments are made for body size, and brain size (whether or not adjusted for body size) is positively associated with intelligence. From these two propositions it would be expected that males would have a higher average level of intelligence than females. Yet it is invariably stated in text books that "gender differences in general intellectual ability are small and virtually non-existent" (Brody, 1992, p. 323) and "there are no overall differences in the scores obtained by males and females on intelligence tests" (Halpern, 1992, p. 63). There seems to be a logical inconsistency between the findings of the larger male brain, the association of brain size with intelligence and the absence of a sex difference in intelligence which calls for resolution.

Ankney and Rushton propose different solutions to the paradox. Ankney accepts the generally held view that there is no sex difference in general intelligence, and he also notes another generally accepted view that females obtain higher means on verbal abilities while males obtain higher means on spatial abilities (e.g. Maccoby & Jacklin, 1974; Hyde & Linn, 1988; Linn & Petersen, 1985; Halpern, 1992). He apparently accepts that these relative male and female strengths in the verbal and spatial abilities are counterbalanced so that they produce equal overall intelligence. The solution he proposes to the paradox is that spatial ability may require more brain tissue than verbal ability. This is an ingenious solution but there is no direct evidence to support it and there may be a simpler solution to the problem.

Such a simpler solution is proposed by Rushton. He questions the belief that males and females have the same mean IQ. He cites the results of the standardization samples of the WISC-R in the United States and Scotland (Jensen & Reynolds, 1983; Lynn & Mulhern, 1991), in both of which males obtained slightly higher means for Full Scale IQ than females. However, the proposition that males have a higher mean IQ than females runs counter to the consensus of opinion in the entire history of intelligence testing and would certainly require the marshalling of a considerable amount of evidence to sustain.

Before considering the issue of sex differences in intelligence, it is useful to look briefly at the other two elements in the paradox, i.e. the sex differences in brain size and the association between brain size and intelligence. Both of these propositions have frequently been rejected. For instance, it is stated in a recent textbook that "relative to body size, there are no sex differences in brain weight" and "there is no evidence that larger brains are, in any way, better than smaller brains" (Halpern, 1992, p. 140). However, there is convincing evidence that both of these assertions are incorrect. Both the Ankney (1992) and Rushton (1992) studies show that brain weight is greater in males even after adjustment is made for body size. Ankney reanalyses the data of Ho, Roessman, Straumfjord and Monroe (1980) on 1261 brains, adjusts the sex differences for body height and surface area, and shows that after this adjustment male brains are about 100 g heavier than female brains. A similar conclusion is reached by Rushton (1992) from an analysis of 6325 American Army personnel, on which he calculates that after adjusting for body height and weight males have a cranial capacity of 1442 cm^3 and females of 1332 cm^3.

Equally securely established is the existence of a positive relation between brain size and intelligence. An approximate measure of brain size can be obtained by measuring head circumference, which correlates approx. 0.8 with brain size (Brandt, 1978). Eleven studies which have taken head circumference or externally measured cranial capacity as approximate measures of brain size all showed statistically significant correlations with intelligence (Lynn, 1990) and subsequent studies summarized by Rushton (1992) confirm this relationship. Direct measurement of brain size by magnetic resonance imaging shows a correlation of 0.35 with intelligence (Willerman, Schultz, Rutledge & Bigler (1991)). It is believed that the facts that males have larger average brain size than females and that brain size is positively associated with intelligence have to be accepted. It is therefore the third leg of the paradox that requires scrutiny, i.e. the issue of sex differences in intelligence.

Two initial steps need to be taken to make progress with this problem. First, it is necessary to define the concept of general intelligence. Three definitions are discussed, namely (a) what is measured by the Wechsler tests; (b) the Burt–Vernon model and (c) the Cattell–Gustafsson model. Secondly, we need to distinguish sex differences in adulthood from those in children and young adolescents. The reason for this is that girls mature earlier than boys and this reduces the intelligence difference. The simplest case is adults in whom the maturation process is complete and this complication is avoided. We therefore start with adults and turn later to children and adolescents.

THE WECHSLER TESTS

A useful starting point for our inquiry consists of an examination of sex differences on the Wechsler tests. These are widely regarded as among the best measures of intelligence. The subtests provide measures of a wide range of cognitive abilities including verbal reasoning, comprehension, numerical, visual, perceptual, spatial and memory abilities which are combined to give a global IQ, described by Kaufman (1990, p. 56) as an "exceptional summary of abilities".

There are a number of versions of the Wechsler tests, all of which have been standardized in the United States and in a number of other countries on representative samples of the population, stratified on the basis of socio-economic status and geographical location. Sex differences on all the standardization samples for which it has proved possible to obtain the data are shown in Table 1. In addition to the standardization samples there are two studies where the WAIS and WAIS-R have been given to married couples and their adopted children for which there seems no reason to suspect sampling bias. Table 1 gives, where available, details of the test, the male and female means on the Full Scale, Verbal and Performance IQs, and the male–female differences in IQ points. Several of the studies do not give the full data (e.g. the number of subjects, the standard deviations, etc.) which is the reason for certain gaps in the table.

It is stated in a recent text book on sex differences in intelligence that "the Wechsler overall IQ does not show sex differences" (Halpern, 1992, p. 64). An examination of the results of the studies set out in Table 1 will show that this statement is incorrect. In all studies males obtain a higher Full Scale IQ than females and these differences are virtually all statistically significant. The mean of the 8 WISC and WISC-R samples is a 2.35 IQ point advantage for males and of the 6 WAIS and WAIS-R samples a 3.08 IQ point male advantage. Males also obtain higher means than females on both Verbal and Performance IQs, contrary to received opinion which holds that females have higher verbal abilities than males (Maccoby and Jacklin, 1974).

It is interesting to note that the male advantage on the Wechsler tests is generally greater among adults than among children and adolescents. This confirms the point that the earlier maturation of females reduces the sex difference in intelligence in childhood and early adolescence. The male advantage in brain size is also greater among adults than among children and young adolescents, as will be seen later in the paper.

Although the consistently higher means obtained by males on all Wechsler samples presents a

Table 1. Sex differences in IQ on the Wechsler tests in various samples and countries

Country	Test	N	Full scale IQ Males Mean	Full scale IQ Males SD	Full scale IQ Females Mean	Full scale IQ Females SD	Full scale IQ M–F Difference	Verbal IQ Males Mean	Verbal IQ Males SD	Verbal IQ Females Mean	Verbal IQ Females SD	Verbal IQ M–F Difference	Performance IQ Males Mean	Performance IQ Males SD	Performance IQ Females Mean	Performance IQ Females SD	Performance IQ M–F Difference	Sample	Reference
United States	WISC	2200	100.8	15.6	99.1	14.4	1.7	101.2	15.3	98.7	14.7	2.5	100.3	15.6	99.7	14.4	0.6	Standardization	Seashore, Wesman & Doppelt, 1950
Greece	WISC	403	92.1	12.5	90.0	11.4	2.1	96.4	13.5	94.7	12.2	1.9	89.0	12.2	86.3	11.7	2.7		Fatouros, 1972
United States	WISC-R	1866	103.1	14.5	101.4	13.5	1.7	103.3	14.7	100.7	13.5	2.6	102.3	14.3	102.1	13.9	0.2		Jensen & Reynolds, 1983
China	WISC-R	2236	101.4	14.8	98.6	15.1	2.8	101.5	14.9	98.5	15.0	3.0	101.0	14.8	98.9	15.2	2.1		Dai & Lynn, in press
Scotland	WISC-R	1361	101.2	14.1	99.4	13.8	1.8	101.6	14.5	98.5	13.4	3.1	100.4	13.6	100.3	14.2	0.1		Lynn & Mulhern, 1991
Israel—Jews	WISC-R	2111	101.7	—	98.5		3.2	101.2		98.3		2.9	101.0		99.1		1.9		Lieblich, 1985
Israel—Arabs	WISC-R	639	102.3	—	98.2		4.1	101.9		97.6		4.3	101.6		97.3		4.3		Lieblich, 1985
Netherlands	WISC-R	2027	100.7	15.1	99.3	14.8	1.4	100.8	15.1	99.2	14.6	1.6	100.4	14.8	99.6	15.4	0.8		Born & Lynn, to appear
United States	WAIS	1700					1.0					1.2					0.1		Wechsler, 1958
Netherlands	WAIS	2100					4.1					4.3					3.9		Stinissen, 1977
United States	WAIS-R	1880	100.9	15.3	98.7	14.9	2.2	100.9	15.1	98.7	14.7	2.2	100.5	15.2	99.1	15.1	1.4		Reynolds, Chastain, Kaufman & McLean, 1987
China	WAIS-R	1979	102.0	14.7	97.0	15.2	5.0	102.2	14.5	96.8	15.0	5.4	101.4	14.8	97.7	15.1	3.7		Lynn & Dai, to appear
United States	WAIS	588	115.2	11.1	112.7	10.8	2.5	115.9	11.7	112.7	10.8	3.2	112.4	11.8	110.9	10.9	1.5	Married couples	Horn, Loehlin & Willerman, 1979
United States	WAIS-R	206	110.9	13.5	107.2	12.6	3.7	109.2	13.2	103.6	12.7	5.6	110.5	13.7	110.3	13.2	0.2	Adopted children	Ilai & Willerman, 1989

Differences of 1.4 and above are stastically significant at the 5% level.

powerful challenge to the consensus view that there are no sex differences in intelligence, this set of results does not provide a wholly satisfactory solution for the issue of the magnitude of the sex differences. The problem is that the Wechslers consists of an arbitrary collection of subtests which has no theoretical rationale. The subtests show a range of sex differences from a consistent female advantage on coding in all samples and sometimes on digit span, to various magnitudes of male advantage on the other subtests. Hence the removal of some subtests and replacements by others would produce different overall sex differences reflected in the Full Scale IQ. Faith in the male advantage on the Wechsler Full Scale IQ is only as strong as faith in the representativeness of the subtests as a good sample of cognitive abilities. This faith is certainly open to challenge. For instance, males outscore females on the mechanical reasoning scale of the Differential Aptitude Test by about 15 IQ points (Feingold, 1988). A case could be made for including a mechanical reasoning subtest in the Wechsler tests. The Wechslers contain subtests of verbal reasoning and non-verbal reasoning, so why not a subtest of mechanical reasoning? The inclusion of a mechanical reasoning subtest would clearly increase the male advantage on the Full Scale IQ.

An attempt to obtain IQs from the Wechslers which has a theoretical rationale has been made by Jensen and Reynolds (1983). They worked on the standardization sample of the WISC-R and their method was to factor analyse the subtest correlation matrix and extract the general factor, identified as Spearman's *g*, and also three further factors identified as verbal, visuospatial and memory abilities. The result is that the *g* factor shows a male advantage of 0.16 *d* (standard deviation units), equivalent to 2.4 IQ points, whereas on the Full Scale IQ the male advantage is 1.7 IQ points. Hence the calculation of scores on the *g* factor increases the male advantage by approx. 40%. The reason for this is that females perform well on the WISC-R subtests with the lowest *g* loadings, viz. coding and digit span, while males perform better on subtests with high *g* loadings such as information and vocabulary. Since the calculation of factor scores weights subjects' scores by the factor loadings, males obtain a higher mean on the *g* factor than they do on the Full Scale IQ.

This procedure does something to improve the credibility of the Wechsler scores but it does not deal fully with the problem that the subtests in the Wechslers may not represent adequately the full range of cognitive abilities. In addition to the absence of a mechanical reasoning subtest in the Wechslers, the tests do not contain subtests of some of the spatial abilities on which there are large male advantages (Linn & Peterson, 1985) and the inclusion of which would increase the overall male advantage on the tests even using the Jensen and Reynolds' factoring procedure.

My conclusion is that the data derived from the Wechslers are a useful starting point for considering the problem of sex differences in intelligence. It is widely considered that the Wechsler tests contain a good mix of abilities and the results of the studies showing a mean male advantage of 3.08 IQ points on the Full Scale IQ among adults provide a rough and ready solution to the problem of sex differences in intelligence. Nevertheless, the atheoretical and arbitrary nature of the subtests which happen for historical reasons to be included in the Wechslers make them theoretically unsatisfying instruments for the quantification of sex differences in intelligence. A better approach is to start with a theoretical model of intelligence and then quantify sex differences in terms of the model. This is the approach we consider next.

THE BURT–VERNON HIERARCHICAL MODEL

A theory based solution to the problem of sex differences in intelligence can be derived from the hierarchical model of abilities of Burt (1949) and Vernon (1950). The model consists of a number of primary abilities which can be combined into two major group factors. These are designated (a) the verbal factor, consisting of verbal comprehension, language and number abilities, and (b) the spatial factor, consisting of spatial abilities. These two group factors can be combined to form the general factor, Spearman's *g*.

To quantify sex differences in intelligence in terms of this model we need measures of the two group factors. We begin with the American data on adults defined as those aged 18 yr and older. For a measure of sex differences in the verbal group factor we can do no better than use the verbal IQs of the standardization samples of the WAIS and WAIS-R. These give male advantages of 1.2 and 2.2 IQ points, which are averaged to 1.7. A closely similar figure of 1.65 IQ points is present in Ramist and

Arbeiter's (1986) report on nearly 1 million students taking the verbal section of the Scholastic Aptitude Test.

To obtain figures for the spatial group factor we rely on Linn and Peterson's (1985) meta-analysis of sex differences in spatial abilities. They propose the existence of three spatial abilities designated visualization, spatial perception and mental rotation, for which they calculate adults *d*s of 0.13, 0.64 and 0.73, respectively. These can be averaged to 0.50, the equivalent of 7.5 IQ points. Combining the male advantage of 1.7 and 7.5 IQ points for the verbal and spatial abilities gives an overall advantage of 4.6 IQ points.

THE CATTELL–GUSTAFSSON HIERARCHICAL MODEL

An alternative hierarchical model of intelligence has been proposed by Gustafsson (1984) on the basis of the earlier model of Cattell (1971). The Cattell–Gustafsson model posits a number of primary abilities which can be aggregated into three second-order factors designated (a) crystallized intelligence (corresponding to the Burt–Vernon verbal factor); (b) visualization (corresponding to the Burt–Vernon spatial factor); and (c) fluid intelligence (corresponding to the Burt–Vernon *g* factor). To demonstrate the model empirically, Gustafsson starts with 16 tests of reasoning, memory, spatial, verbal and educational abilities. The tests were factor analysed by Lisrel and produced the three second-order factors. These three factors were factored again to give a single third-order factor which is identified as Spearman's *g*. This third order factor has its highest correlation with fluid intelligence and slightly lower correlations with visualization and crystallized intelligence. This model "probably incorporates the consensus more than any other" (Bouchard, 1993, p. 34).

To calculate sex differences in terms of this model we can use the *d*s for the verbal and spatial group factors calculated above for Gustafsson's crystallized and visualization factors. Additional data are needed for his third factor of reasoning ability. This can be broken down into verbal and abstract (non-verbal) reasoning. To obtain sex differences on these we take the verbal and abstract reasoning subtests of the 18 yr olds on the four Differential Aptitude Test standardizations (Feingold, 1988). These give *d*s of 0.12 and 0.16, which are averaged to 0.14 equivalent to 2.1 IQ points. Hence for sex differences in terms of the Cattell–Gustafsson model we have male advantages of 1.7, 7.5 and 2.1 IQ points for the verbal, spatial and reasoning abilities, giving an overall male advantage for general intelligence of 3.8 IQ points.

Table 2. Male–Female mean IQ differences in verbal, spatial and reasoning abilities

Verbal abilities	Male–Female IQ differences
WAIS Verbal standardization sample	1.2
WAIS-R Verbal standardization sample	2.2
Mean	1.7
Reasoning abilities	
Verbal—DAT	1.8
Non-verbal—DAT	2.4
Mean	2.1
Spatial abilities	
Spatial visualization	2.0
Spatial perception	9.6
Mental rotation	10.9
Mean	7.5
General intelligence	3.8

MAGNITUDE OF THE EFFECT ON INTELLIGENCE OF SEX DIFFERENCES IN BRAIN SIZE

Three methods for quantifying sex differences in intelligence among adults have now been considered. These consist of adopting (1) the Full Scale IQ of the Wechsler Adult Intelligence Scale, for which six studies give a mean male advantage of 3.1 IQ points; (2) the Burt–Vernon model of the group verbal and spatial factors which give a male advantage of 4.6 IQ points; and (3) the Cattell–Gustafsson model which adds reasoning abilities to the Burt–Vernon verbal and spatial abilities, and which gives a male advantage of 3.8 IQ points. There is not a great deal of difference between the three estimates. To derive the best single figure I would begin by discarding the Wechsler Full Scale IQs on the grounds that these are simply the average of an arbitrary collection of tests with little theoretical rationale. As between the Burt–Vernon and the Cattell–Gustafsson models, the Cattell–Gustafsson is probably to be preferred on the grounds that it includes the important reasoning abilities, which are central to the construct of intelligence. It is therefore proposed to adopt the 3.8 IQ point differential obtained from the Cattell–Gustafsson model and round it up to 4 IQ points as the best estimate of the sex difference in intelligence among adults.

We need to consider now the magnitude of the male advantage for intelligence that would be expected from the larger male brain. This can be estimated as follows. The male–female difference in brain size adjusted for body size is calculated by Ankney (1992) at approx. 100 g and the pooled standard deviation for brain size is 128 g. Hence males have a brain size advantage of 0.78 standard deviation units. The correlation between brain size measured by magnetic resonance imaging and intelligence has been calculated by Willerman *et al.* (1991) at 0.35. The male advantage for intelligence accruing from greater brain size is therefore $0.78 \times 0.35 = 0.27$ standard deviation units = 4 IQ points. Thus the theoretical magnitude of the male advantage in intelligence arising from the larger male brain gives a close fit to the data.

SEX DIFFERENCES IN INTELLIGENCE OUTWITH THE UNITED STATES

Hitherto the data on sex differences in intelligence have been obtained from the United States, except for the Wechsler results shown in Table 1. We consider now whether the male advantage found in the United States is present in other countries. Data for subjects aged 18 yr plus (17 yr in the case of Northern Ireland) are shown for five countries in Table 3. The table gives figures for verbal, reasoning and spatial abilities and averages these to give a figure for general intelligence. The figures in the table are male–female IQ differences, as in Table 2. The first row summarizes the American results estimated above. For Britain, data for verbal comprehension are taken from Lynn and Wadsworth's (1993) report on vocabulary obtained on a representative sample of approx. 4000 26 yr olds, and for verbal reasoning, non-verbal reasoning and spatial abilities the data are taken from 18 yr olds in the British standardization of the Differential Aptitude Test (Lynn, 1992).

Table 3. Sex differences in verbal, reasoning, spatial and general intelligence in six countries

Country	Age(yr)	Test	*N*	Verbal	Reasoning	Spatial	General	Reference
United States	18 +	Numerous	—	1.7	2.1	7.5	3.8	(See above)
Britain	18	Differential aptitude	4367	1.2	3.7	7.2	4.2	Lynn & Wadsworth, 1993; Lynn, 1992
Norway	18–65	Dureman–Sälde	3064	0.7	11.5	11.5	7.7	Nystrom, 1983
Sweden	18	Swedish scholastic aptitude	31342	0.6	8.1	8.4	5.7	Stage, 1988
Indonesia	18–24	Tiki-T	936	1.7	2.2	4.3	2.5	Drenth, Dengah, Bleichrodt, Soemarto & Poespadibrata, 1977
Northern Ireland	17	AH5	14936	4.2	5.5	6.9	5.5	McEwan (no date)

Differences of 1.2 IQ points are statistically significant at the 5% level.

The data for Norway are for 3044 adults invited to a hospital for a health examination and given the Dureman–Sälde Test. The reasoning scale consists of geometric design problems. The slightly high male advantage is probably inflated because the reasoning test does not include verbal reasoning in which females score a little higher than on non-verbal reasoning [see Table 1 and Lynn (1992), for the British DAT data].

The data for Sweden came from the Swedish Scholastic Aptitude Test taken by applicants for admission to universities. The test consists of verbal comprehension and reading comprehension, averaged to give verbal ability, quantitative reasoning and spatial ability. The Swedish SAT also contains a test of general knowledge which shows a male IQ of 104.8 but this is not used here.

The data for Indonesia came from university students in Java tested with an omnibus test of Dutch construction called the Tiki-T. The results for Northern Ireland came from a 25% sample of all children in grade 13 in secondary schools tested with the AH5. This test consists of verbal and non-verbal scales comprising, respectively, verbal comprehension and reasoning, and non-verbal reasoning and spatial problems. The two scales are averaged to give a measure of reasoning ability.

The upshot of these results is that the magnitude of the sex differences in these five countries is a little greater than in the United States, with the exception of Indonesia where the data came from university students where females are probably more highly selected than males. The overall pattern of results suggests that rounding the American sex difference of 3.8 IQ points to 4.0 as the nearest whole number is probably the correct decision and applying the same procedure to the British data gives the same result. We will therefore stick with 4 IQ points as the best estimate of the sex difference in general intelligence among adults.

SEX DIFFERENCES IN EXAMINATION PERFORMANCE

Intelligence is a major determinant of performance in academic examinations, with which it typically correlates at around 0.6 (Eysenck, 1979), and it is therefore a corollary of the male advantage in intelligence that there should also be a male advantage in examination performance. Of course success in examinations has other determinants such as the strength of motivation and work effort expended in mastering the syllabus. It is possible that females might be more motivated and that this would compensate for their lower mean intelligence, producing no difference in examination performance. However, we proceed on the assumption that this is not the case and that the higher male mean IQ will express itself in better performance in examinations.

In the United States there are extensive data on sex differences in examination performance on the SAT which is taken by approaching one million high school students each year for college entrance. The results for the Mathematics exam for 1984 are reported by Arbeiter (1985). The mean scores for males and females were 495 and 449, respectively, a difference of 0.40 *d*. On the verbal SAT there is a difference favouring males of 0.11 *d*, as already noted (Ramist & Arbeiter, 1986).

There are some useful data from Britain on sex differences in performance in examinations taken in late adolescence and early adulthood. At the end of secondary school many English adolescents taken the Advanced ("A") level examination, the results of which are used for university entrance, so that this examination serves the same purpose as the SAT in the United States. Generally students in England take three subjects in this examination. The results are graded on a scale running from A to E, and these grades are commonly converted to numbers running from 5 to 1. Using this conversion, sex differences in performance on the A level examination for those applying for admission to universities have been analysed for 112,587 students for the year 1989 by Mar-Molinero (1991). Of the students obtaining the top scores of 13–15 points, 23.6% were male and 17.6% female.

There is a similar male advantage in degree results at British universities. Students in Britain are normally graded on the basis of their examinations into class one, class two division one, class two division two, class three and pass. It has been shown that performance in these examinations is significantly correlated with intelligence tested with the AH5 at a magnitude of about 0.4 (Heim, 1968). This correlation is probably lower than the 0.6 given above because of the restriction of range.

Sex differences in examination performance at all British universities have been reported by Clarke (1988) for the late 1970s. Results are analysed for 125,670 male and 71,737 female graduating students, the smaller number of females suggesting that they are more highly selected. Nevertheless, 9% of males and 5% of females obtained first class degrees. Results for the two elite British universities of Oxford and Cambridge have also been analysed. Goodhart (1988) gives the results for Cambridge for the 1987 examinations taken by 8484 students of which 17.9% of men and 8.5% of women obtained firsts. The number of women students at the university is about half that of men, again suggesting that the women are more highly selected. Similar results have been reported for Oxford university for the years 1984–88 by McCrum (1991). Among 12,364 students taking final examinations, 16.7% of men obtained firsts as compared with 9.1% of women. The superior performance of males is present in both Arts and Sciences.

It has sometimes been suggested that the higher proportion of males obtaining firsts can be explained by a bias of predominantly male examiners against women students, but this cannot operate at Oxford or Cambridge because at Cambridge students write only the initials of their first names on their examination scripts and in some subjects are identified by codes rather than names, so their sex is unknown to the examiners. At Oxford all examination scripts are randomly numbered and marked blind with very minor exceptions (Davies & Harré, 1989). This makes it improbable that examiner bias can explain the sex differences in examination performance.

These sex differences in examination performance in A level and university degrees are about what would be expected from the sex differences in intelligence. With a male–female mean IQ difference of 4 IQ points, there is an excess of males of approx. 30% with IQs over 120. This is close to the 34% excess of males achieving 13–15 points in the A level examinations. At an IQ of 130 plus, there is an excess of approx. 89% males. This corresponds closely to the excess of males obtaining first class degrees, which is 80% for all British universities and a little greater for Oxford and Cambridge.

A further point is that it is easier to get 13–15 points in A level than it is to get a first class degree. In the Mar-Molerino (1991) data, 23,458 young people obtained 13–15 A level points, while in the Clarke (1988) data 15,250 students obtained firsts. It is a well-known statistical theorem that where two populations differ in their mean values on a characteristic, the difference between the proportions of the two populations falling above a given threshold becomes progressively greater with distance from the mean. The sex differences in obtaining 13–15 A level points and a first class degree evidently conform to this principle. Because it is harder to get a first class degree, the proportion of males succeeding is greater.

An alternative hypothesis sometimes advanced for the better male performance in examinations among high intelligence groups is that there is a greater male variability in intelligence around the same mean. This would produce a greater proportion of high IQ males and hence better examination performance. The evidence for the greater male variability hypothesis has recently been reviewed by Feingold (1992). He concludes that there are no sex differences in variability for most verbal abilities, verbal reasoning and abstract reasoning, but there is greater male variability in mathematical, spatial and mechanical reasoning abilities. Probably for most academic subjects the verbal and reasoning abilities are the most important and the absence of a sex difference in variability in these cannot explain the better performance by males. The greater male variability in mathematical, spatial and mechanical reasoning abilities may contribute to the better male performance in subjects for which these abilities are important, e.g. mathematics, physics, engineering, etc. but probably the major factor responsible for better male performance in virtually all academic disciplines is the higher male mean IQ shifting the whole distribution upwards and producing a substantially greater proportion of males among high IQ groups.

SEX DIFFERENCES IN CHILDHOOD AND ADOLESCENCE

We turn now to the question of sex differences in intelligence and brain size during childhood and adolescence. The problem is more complicated than is generally appreciated because boys and girls mature at different rates. Girls mature earlier than boys but the timing of the sex differences in maturation rates varies for different physical characteristics. In the calcification of the teeth, girls begin to accelerate ahead of boys at the age of 6 yr and are about 6 months ahead of boys up to the age of 15, after which boys catch up (Demirjian, 1978). In height and weight, the growth of girls begins to accelerate at about the age of 8 yr, when they overtake boys. Girls retain greater average heights than boys up to the age of 14 yr and greater average weights up to 15 yr.

These sex differences in maturation rates are also present in the growth of the brain, although the onset of the earlier growth spurt in girls is not synchronized with those in height and weight. The brain size of girls begins to increase relative to that of boys from about the age of 8 yr and the sex differential is at its minimum between the ages of 11–14 yr. However, unlike height and weight, the brain size of girls does not surpass that of boys. From the age of about 15 yr the growth of girls is virtually complete for height and brain size, but boys continue to grow in both stature and brain size up to the age of 18 yr. These age trends are present with minor inconsistencies in both head circumference and cranial capacity.

These generalizations are illustrated in Table 4. The first row sets out data for height, expressing girls' stature as a percentage of boys'. Note that girls are taller than boys between the ages of 8–14 yr, reflecting the earlier female growth spurt. Row 2 shows similar data for weight illustrating the same phenomenon, except that the greater weight of girls lasts until 15 yr. Row 3 shows the age trend for head circumference, a good proxy for brain size. Note here that the female head circumference grows faster than the male from the age of 9 yr and the male–female differential is at its lowest between the ages of 11–14 yr. However, whereas girls are taller and heavier throughout these years, they do not develop larger brains. Rows 4 and 5 give figures for the cranial capacities of boys and girls, calculated from the head length, width and height data given by Roche and Malina (1983, p. 483) using the Lee and Pearson (1901) formula for converting these dimensions to cranial capacities. The formula is given and used by Rushton (1992) whose figure for adults is entered in the 26 yr old column. Row 6 gives female cranial capacity as a percentage of male. These figures show the same age trend as head circumference, the male–female differential narrowing between the ages of 11–14 yr, and thereafter increasing as boys continue to grow at a faster rate than girls.

It is evident from the data set out in Table 4 that sex differences in brain size fluctuate over the course of childhood and adolescence, growing smaller between the ages of 11–14 yr and increasing from the age of 14 yr onwards. We should expect sex differences in intelligence to fluctuate in synchrony with these fluctuations in brain size differences. A number of predictions regarding sex differences in intelligence can be made from the brain size differences, of which six are set out below.

Prediction 1

Sex differences in brain size between the years of 5–17 are smaller than they are at 18 plus. Therefore the intelligence differences should be smaller. We have already seen that sex differences among children and adolescents measured by the Wechsler tests are generally smaller than among adults (2.3 compared with 3.1 IQ points), providing our first corroboration of this prediction. For a further examination of this question we adopt the sex difference in verbal abilities for 5–17 yr olds calculated in the Hyde and Linn (1988) meta-analysis at -0.10 *d* (favouring females). For spatial abilities the sex differences are 0.37, 0.73 and 0.13 calculated by Linn and Peterson (1985) for the three abilities, which can be averaged to 0.41 *d*. There is no meta-analysis of sex differences for reasoning, but we will probably not go far wrong if we set this at zero considering that this is the result of the standardization sample of the Standard Progressive Matrices for aged 6–15 (Raven, 1981, p. 26). Averaging the three abilities in accordance with the Cattell–Gustafsson model, as for adults set out above, we arrive at a sex difference favouring males of 0.10 *d* or 1.5 IQ points. Hence the prediction from the brain size sex differences is confirmed; a difference favouring males is present over the age range 5–17 yr but is less than among adults.

Prediction 2

The above calculation of sex differences over the age range 5–17 yr is a rough and ready approach to the problem because of the fluctuations in the sex differential in brain size at different ages. For a more precise prediction we take age 14 yr at which the sex differential for brain size is at its smallest and is only 53% of the differential among adults provided by Rushton (1992). Hence the IQ difference of 4 IQ points for adults predicted earlier in this paper from the difference in adult brain size should be reduced to 53% of this figure among 14 yr olds and equal to 2.1 IQ points or 0.14 *d*. The data in Table 4 show actual sex differences among 14 yr olds for general intelligence of 0.19 *d* (Visser, 1987), while the DAT data give *d*s as averages of the four tests of 0.01 for the United States (Feingold, 1988) and 0.13 for Britain (Lynn, 1992). These are both underestimates of the male advantage because the DAT spatial test does not include the spatial abilities in which males are particularly strong. Nevertheless, if we average the three results we have a male advantage of 0.11 *d* which is fairly close to the theoretical prediction of 0.14 *d*.

Table 4. Age trends in stature, weight, head size, cranial capacity and various measure of intelligence *d*s of 0.07 and above are statistically significant at the 5% level

Variables	Units	Age (yr) 5	6	7	8	9	10	11	12	13	14	15	16	17	18	26	Reference
Stature	Female as	98.6	98.6	98.5	101.1	101.0	101.7	100.3	101.3	101.3	102.0	99.3	97.1	93.6	92.9		Roche & Malina, 1983, p. 204
Weight	% of male	96.7	96.3	96.5	104.7	104.4	106.0	101.5	103.8	106.6	113.5	104.9	98.6	87.4	86.3		Roche & Malina, 1983, p. 204
Head circumference	Female as % of male	98.0	97.5	97.6	97.6	98.1	98.1	99.0	99.5	99.5	99.1	98.2	97.7	97.3	96.4		Roche & Malina, 1983, p. 466
Cranial capacity males	cm^3	1239.1	1250.5	1268.6	1285.3	1301.1	1317.5	1329.5	1345.4	1360.7	1380.1	1409.2	1428.1	1447.4		1462	Roche & Maline, 1983; Rushton, 1992 males
Cranial capacity females	cm^3	1109.8	1128.4	1144.8	1164.3	1178.2	1190.8	1215.1	1240.4	1258.1	1277.2	1289.5	1301.8	1291.1		1266	Roche & Malina, 1983; Rushton, 1992 females
Cranial capacity	Female as % of male	89.6	90.2	90.2	90.6	90.6	90.4	91.4	92.2	92.5	92.6	91.5	91.2	89.2		86.6	Roche & Malina, 1983, p. 483
Verbal reasoning	*d* (SD units)							−0.04					0.21				Emmett, 1950
Abstract reasoning	*d*				0.00			−0.07				0.15					Lynn & Wadsworth, 1993
Verbal comprehension	*d*				−0.22							0.05				0.08	Lynn & Wadsworth, 1993
Abstract reasoning	*d*							0.06		0.12			0.29				Paspalanova & Shtetinski, 1983
Reasoning ability	*d*								0.19		0.20		0.33				Visser, 1987; Owen & Lynn, 1993
Verbal ability	*d*								−0.14		−0.05		0.03				Visser, 1987; Owen & Lynn, 1993
Spatial ability	*d*								0.29		0.42		0.50				Visser, 1987; Owen & Lynn, 1993
General intelligence	*d*								0.11		0.19		0.28				Visser, 1987; Owen & Lynn, 1993
Verbal reasoning	*d*										−0.01	0.02	0.04	0.08	0.12		Feingold, 1988
Abstract reasoning	*d*										0.00	0.04	0.09	0.10	0.16		Feingold, 1988
Numerical ability	*d*										−0.10	−0.03	−0.01	0.14	0.24		Feingold, 1988
Space relations	*d*										0.15	0.18	0.24	0.24	0.34		Feingold, 1988
Verbal reasoning	*d*										0.15	0.04	0.10	0.28	0.25		Lynn, 1992
Abstract reasoning	*d*										0.06	0.08	0.08	0.19	0.25		Lynn, 1992
Numerical ability	*d*										0.24	0.18	0.20	0.41	0.54		Lynn, 1992
Space relations	*d*										0.19	0.28	0.30	0.43	0.48		Lynn, 1992

Prediction 3

Longitudinal studies in which the same subjects take intelligence tests at different ages should show a sex difference moving in favour of females from age 11–14 yr and then moving in favour of males from the age of 15 onwards, in parallel with the brain size differentials. An early study showing this effect was published by Emmett (1950) and the results are shown in row 7 of Table 4. The study consisted of 3661 English children who took the Moray House Verbal Reasoning test at the age of 11 yr, at which age girls performed slightly better ($d = -0.04$). The same children took a harder version of the test at an average age of 16 yr and at this age boys obtained a significantly higher mean ($d = 0.21$). This result should have alerted developmental psychologists to the possibility of sex differences in the rate of maturation such that a negligible sex difference in intelligence at the age of around 11 yr develops into a male advantage in later adolescence, but it passed unnoticed and is not cited in contemporary treatments of this question.

The same effect is present in the British 1946 birth cohort study of a representative sample of all babies born in Britain in the first week of March of 1946 and numbering approx. 4000. The sample were given tests of abstract reasoning at ages 8, 11 and 15 yr and verbal comprehension at ages 8, 15 and 26 yr and the results are shown in rows 8 and 9 of Table 4. Note that for abstract reasoning there is no sex difference at age 8, a statistically significant female advantage at age 11 turning into a statistically significant male advantage at age 15. The same age trend is evident for verbal comprehension although the female advantage is generally greater for this ability, as would be expected from the Hyde and Linn (1988) meta-analysis of the American data. At age 8 females are ahead, but by the ages of 15 and again at age 26 males achieve higher scores.

Prediction 4

Cross sectional studies should confirm the trend of small sex differences up to the age of around 12–14 yr after which the male advantage grows progressively greater. Some data given in row 10 show this effect for the Culture Fair Test standardized on 1078 11, 13 and 16 year olds in Bulgaria. Data for South African whites for approx. 1000 for each age group of 12, 14 and 16 yr olds for reasoning, verbal and spatial abilities and for the average of these representing general intelligence are set out in rows 11–14 and further exemplify this trend. Note that the male advantage increases progressively over the 4 yr period. At age 12 the sex difference for general intelligence is 0.11 d, virtually the same as the difference of 0.10 d for the whole period of childhood and adolescence calculated under Prediction 1 above. At age 14 the sex difference has increased to 0.19 d, and at age 16 it has increased further to 0.28 d (4.2 IQ points, closely similar to the adult differences shown in Table 2).

Prediction 5

Female brain size as a percentage of male, whether measured by cranial capacity or head circumference, falls steadily from the age of 14–18 yr. Hence female intelligence relative to male should also decline over this age range. The best data come from the standardization samples of the Differential Aptitude Test in the United States and Britain. The American data averaged for four standardization samples and based on approx. 200,000 subjects are shown for verbal reasoning, abstract reasoning, numerical ability and spatial ability in rows 15–18. Note that the male advantage grows steadily over the 5 yr period in tandem with the brain size advantage. Data for the British standardization sample based on approx. 10,000 subjects and displayed in rows 19–22 show the same trend.

Prediction 6

A shift towards a greater male advantage from the age of 14 yr onwards should show up in mathematical ability as a function of general intelligence and verbal, reasoning and spatial abilities. The prediction is confirmed by the Hyde, Fennema and Lamon (1990) meta-analysis of mathematical abilities. They calculate ds for ages 5–10, -0.06 (favouring females); ages 11–14, -0.07; ages 15–18, 0.29 (favouring males); ages 19–25, 0.41; and ages 26 +, 0.59. The large male advantage in mathematics is only present after the age of 15 yr.

My conclusions to this section on developmental trends in sex differences in brain size and intelligence are (1) the sex differences in intelligence vary at different ages so that aggregating them for all ages and concluding in the manner of many contemporary textbooks that no differences exist is no longer a satisfactory approach to the question; (2) in general sex differences in intelligence fluctuate in tandem with sex differences in brain size; (3) sex differences in intelligence are about 1.5 IQ points up to the age of 14–15 yr and thereafter increase steadily to approx. 4 IQ points among adults.

DIFFERENT BRAIN ORGANIZATION IN MALES AND FEMALES

It is an axiom of this paper that the amount of brain tissue is a determinant of intelligence. This applies (a) to the brain as a whole and intelligence as a whole, considered as the sum of the major abilities, and (b) to parts of the brain and the abilities these parts serve. Two of the major abilities are the verbal and spatial abilities and these are located, in right-handed individuals, largely in the left and right hemispheres, respectively. Some people have relatively strong verbal abilities and it might be expected that these would have a large left hemisphere relative to the right. This is apparently the case according to a study by Yeo, Turkheimer, Raz and Bigler (1987) who obtained a correlation of 0.57 between relative hemisphere size and superiority of verbal or non-verbal intelligence. There is no doubt that the relative strength of verbal and spatial abilities differs between males and females, the adult male advantage being much less for verbal abilities than for spatial abilities (estimated at 0.13 *d* and 0.51 *d* respectively earlier in this paper). Do females therefore have larger left hemispheres to accommodate their relatively strong verbal abilities? Apparently not, according to De Lacoste, Adesanya and Woodward (1990) who found in a study of 69 post-mortem brains that the male brain has a surface area approximately one standard deviation greater than the female, consistent with Ankney's (1992) results, but that the female brain does not have a relatively larger left than right hemisphere. How therefore is the female brain organized to give stronger verbal abilities? A solution to this problem has been proposed by McGlone (1980). She noted that females are less adversely affected than males by aphasia following injury to the left hemisphere. To explain this she proposed that females have verbal abilities located in their right as well as their left hemispheres, so that if the left hemisphere is damaged verbal functions continue to be served by the right hemisphere. Since this theory was advanced further evidence has appeared to support it. Strauss, Wada and Hunter (1992) found that damage sustained to the left cerebral hemisphere by infants in the first year of life has a greater adverse effect on subsequent language abilities in males than in females, suggesting that females can develop verbal abilities in their right hemispheres more easily than males. A recent discussion of the evidence on this issue by Kimura and Hampson (1992) is generally favourable to the theory. If the theory is correct, females must have about the same amount of brain tissue devoted to verbal abilities as males (i.e. all the left hemisphere plus some of the right) which explains the fact that female verbal abilities are about the same, or only marginally lower, than male. Female spatial abilities, however, will be rather substantially weaker than male, because the female right hemisphere is smaller than the male and some of it has been given over to verbal abilities.

THE SOCIOBIOLOGY OF SEX DIFFERENCES IN INTELLIGENCE

There are three problems in the sociobiology of sex differences in brain size and intelligence which require solution in evolutionary terms, namely (a) why have males evolved stronger spatial abilities than females; (b) why have males evolved larger brains and stronger verbal and reasoning abilities as well as stronger spatial abilities and (c) why males maturate more slowly than females.

The question of the evolution of stronger spatial abilities among males is relatively straightforward. It is generally believed that the hominids evolved as omnivorous hunter gatherers and that males specialized in hunting and females in gathering and child rearing (e.g. Lovejoy, 1981; Lynn, 1987; Watson & Kimura, 1991). This division of labour between the sexes can be seen today among primitive peoples. The specialization for hunting required strong spatial abilities to enable males to throw stones and spears accurately, formulate hunting strategies and to construct tools and weapons for killing and dismembering their prey. Females has less need for spatial abilities and so did not develop them so strongly.

The second problem is why males have also evolved stronger verbal and reasoning abilities than females and hence, together with the stronger spatial abilities, greater average intelligence. Two solutions are proposed. Firstly, males probably have greater intelligence than females for the same reason that they have greater height, weight and physical strength. The reason for these sexual dimorphisms in height and strength is generally considered by sociobiologists to be that throughout most of the animal kingdom males compete with each other to secure mates but females do not (Wynne-Edwards, 1962; Wilson, 1975). Typically among mammals competition between males leads to the formation of dominance hierarchies and only the higher status males have access to females. Competition between males for access to females is known as sexual selection and characteristics facilitating success in intra-male competition such as strength, size and physical prowess become selected for. During the evolution of the hominids, intelligence would have become an important determinant of success in male competition for status in the dominance hierarchy enabling those who possessed it to form useful alliances, to exercise self-control over the overt display of aggression to seniors, to demonstrate leadership qualities in hunting and warfare and to out-talk the less intelligent in verbal confrontations. In contemporary societies intelligence is a significant determinant of rank indexed by socio-economic status, with which it is correlated at around 0.46 (Jencks, 1972). No doubt this association between intelligence and rank has been present throughout several million years of hominid evolution. The verbal and reasoning abilities would have been quite as important as the spatial abilities for securing status and reproductive success and would have placed males under selection pressure for the enhancement of these abilities.

There may also be a second reason for the evolution of greater intelligence in males. Possibly the male specializations in hunting and the making of artifacts was more generally cognitively demanding than the female specializations in gathering plant foods and child rearing. The female specializations of gathering and child rearing are performed quite satisfactorily by all primate species much less intelligent than homo sapiens, but there is no other primate species capable of the male specializations of hunting prey and of constructing the necessary weapons and tools for this purpose.

The third problem is why males mature later than females in regard to height, brain size and intelligence. I suggest an answer to this problem along the following lines. In the case of females it is advantageous to begin reproducing as soon as possible and this means as soon as they are sufficiently mature physiologically to produce babies and look after them. This is apparently around the age of 12 yr or so. Females at this age have no difficulty in mating because there are always plenty of males willing to mate with them. The problem for males is more difficult. In order to mate they have to secure rank in the male dominance hierarchy. If 12-yr-old males attempted to mate with 12-yr-old females they would be thrashed by older dominant males or, in contemporary civilized societies, sent away to correctional institutions. These experiences would be damaging to self confidence and counter-productive. Furthermore, young females are not keen to mate with young males but prefer older males who have demonstrated that they have good fitness characteristics. Thus in order to secure mates young males have to acquire the cognitive skills and experience necessary to work their way into the dominance hierarchies and the acquisition of these cognitive skills and experience takes an extended period of time.

CONCLUSIONS

The problem raised by Ankney (1992) and Rushton (1992) is that males have larger brains than females, that brain size is positively correlated with intelligence, but that, according to the consensus view, there is no sex difference in intelligence. The paradox is easily resolved. The consensus view that there is no sex difference in intelligence is wrong. Among adults males have a higher mean IQ than females of approx. 4 IQ points, precisely the advantage that can be predicted from their larger brains. Among children the intelligence difference is smaller because of the earlier maturation of girls.

How has it come about that so many experts have asserted that there is no sex difference in intelligence? There are probably two explanations. Firstly, they have forgotten that the human brain has a right hemisphere which houses spatial abilities. Most intelligence tests consist largely or entirely of verbal and reasoning problems on which sex differences are much smaller than on spatial problems. No commercially available intelligence tests contains spatial problems involving three-dimensional rotation on which males outperform females by 11 IQ points (Linn & Peterson, 1985). If an intelligence tests were to contain these problems males would of course score higher than females. The second factor that has misled psychologists is that girls mature earlier than boys, a fact long known in the world of human biology but which has hardly penetrated psychology. Most intelligence test data are obtained from children and young adolescents, particularly over the age range 8–14 yr when the earlier maturation of girls accelerates their physiological development and brain size as compared with boys. If we take largely verbal intelligence tests administered to 8–14 yr olds it is easy to demonstrate that there is no appreciable sex difference in intelligence, and sometimes that females obtain higher means than males, just as if we measure the heights and weights of 8–14 yr olds we can demonstrate that females are taller and heavier than males. It is the concentration of attention on the results of verbal and reasoning tests obtained mainly from children and young adolescents that has misled so many psychologists for so many decades to the erroneous conclusion that there is no sex difference in intelligence.

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